How To Get The Most From Your Electric Motors

ELECTRICAL APPARATUS SERVICE ASSOCIATION
EASA

Reliable Solutions Today

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Preface

This booklet was prepared by the Electrical Apparatus Service Association (EASA). It provides "Reliable Solutions Today" that will help you get the longest life and most efficient operation from your general purpose, three-phase AC motors.

EASA is an international trade organization of electromechanical sales and service firms throughout the world. Through its many engineering and educational programs, EASA provides members with a means of keeping up-to-date on materials, equipment and state-of-the-art technology.

When it comes to sales, application, service and maintenance of motors, generators, drives, controls, and other electromechnical equipment, look to EASA and EASA members for "Reliable Solutions Today." EASA members have the experience and professionalism to engineer energy-efficient solutions for your complete motor system. To be assured of quality workmanship and performance, always look for the EASA logo.

Reliable Solutions Today!

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Maintenance

Proper maintenance and operation are the keys to getting the most from your general purpose, three-phase AC electric motors and other in-plant electrical equipment. An effective maintenance program will minimize unscheduled outages and downtime.

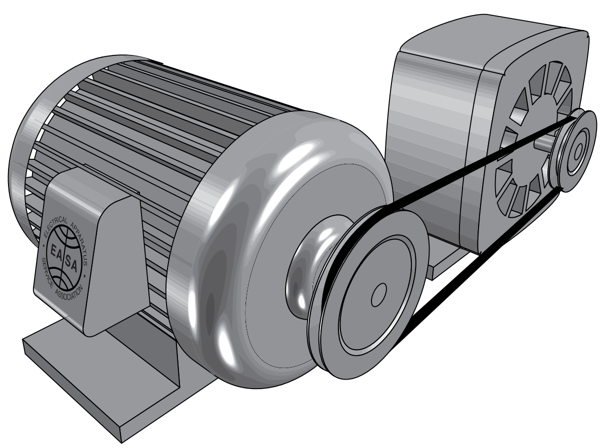
■ **Preventive Maintenance.** Most maintenance departments schedule routine preventive maintenance procedures at regular intervals. These should include lubrication, cleaning, inspection and testing. A complete log of the tests and maintenance performed on a motor should be maintained.

■ **Predictive Maintenance.** A predictive maintenance program consists of plotting trends of test values for insulation resistance and vibration. The trend lines can then be projected to determine when corrective action will be necessary.

A routine maintenance program should identify and correct the more common conditions that may negatively affect motor performance, including:

✔ Insufficient ventilation	✔ High ambient temperature
✔ Mechanical misalignment	✔ Improper V-belt application
✔ Improper lubrication	✔ Excessive moisture
✔ Contamination	✔ Sustained overload
✔ Abnormal voltage	✔ Excessive vibration

These conditions may decrease motor efficiency and, in turn, reduce overall system efficiency. The end results are increased energy consumption, decreased reliability, and reduced operating life.



For example, insufficient ventilation or high ambient temperatures cause the winding resistance to increase, reducing motor efficiency, and potentially resulting in overheating. Excess temperatures also may be due to poor maintenance or misapplication, and likewise will reduce motor operating life and increase energy consumption.

Friction may also gradually increase within the driven machine. This could be caused by dirt buildup on a fan, an impeller rubbing on a pump, worn parts, misaligned couplings or sheaves, or inadequate lubrication.

■ **Lubrication.** Too much lubricant is a major cause of premature motor failure. Excess grease is eventually forced out of the bearing housings and begins dripping on the motor windings, resulting in early winding failure. Overlubrication also can reduce bearing life and motor efficiency.

To lubricate standard-duty motors, follow the original manufacturer's specifications. Begin by cleaning the grease fitting and removing the drain plug. After adding the new grease, run the motor for about an hour before reinstalling the drain plug. This purges excess grease without damaging the windings. If the motor manufacturer's lubrication specifications are not available, follow these recommendations.

Table 1. Lubrication Guide

RPM	Frame Range	Type Of Service	
		8 Hours/Day	24 Hours/Day
3600	143T-256T	*	*
	284TS-286TS	6 months	2 months
	324TS-587US	4 months	2 months
1800	143T-256T	*	*
	284T-326T	4 years	18 months
	364T-365T	1 year	4 months
	404T-449T	9 months	3 months
	505U-587U	6 months	2 months
1200 and below	143T-256T	*	*
	284T-326T	4 years	18 months
	364T-449T	1 year	4 months
	505U-587U	9 months	3 months

* Bearings in these motors often cannot be relubricated. They should be replaced at least every 5 years for 8 hour/day service, or every 2 years for 24 hour/day service.

■ **Cleaning.** It is extremely important to keep air passages clean so that the motor can dissipate the heat it develops. The cooling fins of totally enclosed, fan-cooled motors must also be kept free of dirt and debris, because they are the only means of dissipating heat from these machines. To assure proper cooling, make certain nothing prevents sufficient amounts of fresh air from reaching the motors.

■ **Insulation Resistance Testing.** One of the most useful tests for determining when to remove a motor from service for overhaul and/or rewinding is the insulation resistance test. To be effective, this test must be conducted at regular intervals, typically annually. The results must also be recorded for comparison with future readings. This is known as "trending." If the results show a downward trend, the test should be performed more frequently.

Caution! Before testing, lock out and tag out the electrical supply. The frame must be grounded at all times. Discharge the windings against the frame after every test.

When possible, the windings should be at room temperature for the insulation resistance test. Begin by measuring and recording the temperature of the windings. Be sure the readings are accurate. Making a mistake here will cause errors in the results.

Next, for motors rated up to 600 volts, use a 500-volt megohmmeter to measure the insulation resistance between the windings and the motor frame.

Temperature Correction. Insulation resistance changes considerably with temperature, so readings should be corrected to a base temperature, usually 40° C (see Figure I).

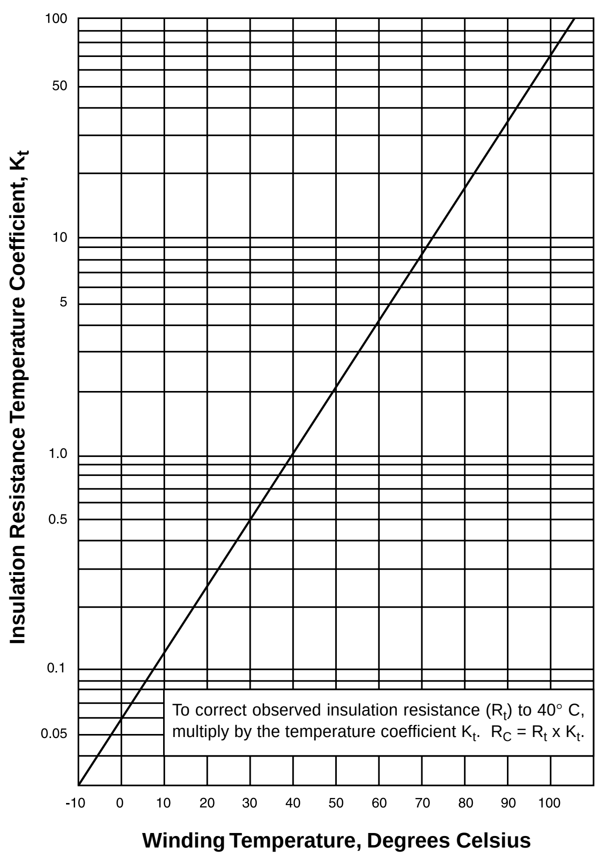


Figure 1. Insulation Resistance Temperature Correction

To correct insulation resistance readings to the reference temperature, use the following formula:

$$R_c = R_t \times K_t$$

Where:

R_c = insulation resistance (in megohms) corrected to 40° C

R_t = measured insulation resistance (in megohms) at temperature t (° C)

K_t = insulation resistance temperature coefficient at temperature t (° C)

Example: Winding temperature t = 68° F = 20° C

Measured resistance R_t = 800 megohms

Referring to Figure I, find the insulation resistance temperature coefficient:

K_t = 0.25

Multiply 800 megohms times 0.25 to find the corrected resistance:

$R_c = R_t \times K_t$

$= 800 \times 0.25$

$= 200$ megohms

Plot the corrected insulation resistance readings for each test on a chart for reference and trending. The corrected reading of 200 megohms from the above example is shown at "0 months" in Figure 2.

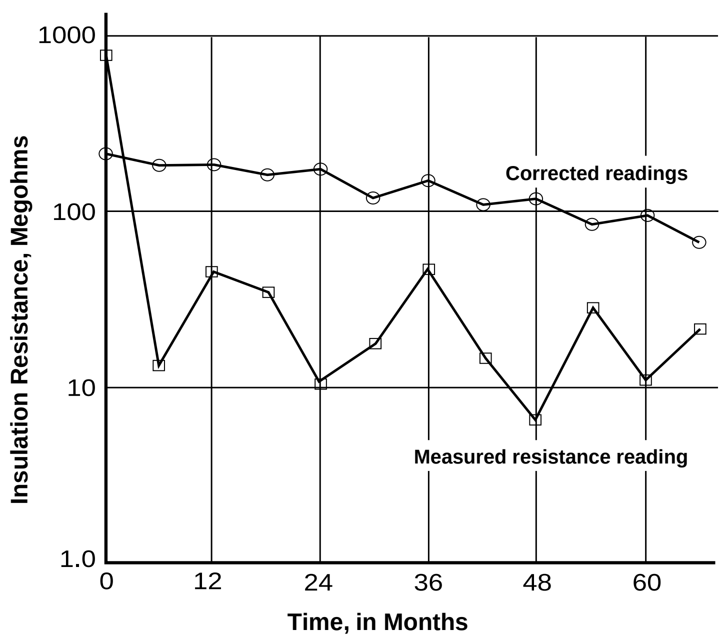


Figure 2. Corrected Insulation Resistance Readings

As long as the corrected readings for insulation resistance on the graph remain fairly level, the insulation system is in good condition. High humidity can cause resistance values to drop, so lower resistance readings on one test do not always mean the insulation is beginning to deteriorate. (For this reason it is a good idea to take and record humidity readings for each test.) If resistance drops for two or three successive tests, further investigation is warranted, and the motor may need to be removed from service.

The recommended minimum insulation resistance to ground, R_{Min}, when measured at or corrected to 40° C, is given by:

R_{Min} = n + 1, in megohms

Where: n is the motor's rated voltage, expressed in kilovolts.

■ **Vibration Analysis.** Vibration analysis is extremely helpful in extending the useful life of a motor. Regularly checking for vibration can detect bearing wear, mechanical looseness, misalignment, defective belts, defective rotors, and electrical unbalance, among other things.This will help pinpoint the source and probable cause of the trouble.

To be effective, this test must be conducted at regular intervals, typically annually. The results must also be recorded for comparison with future readings.

Early detection of vibration problems can reduce the number of unscheduled shutdowns and help prevent avoidable equipment damage.

Service Conditions

Motors must be properly selected with respect to the known environmental and operating service conditions, defined by the National Electrical Manufacturers Association (NEMA) as "usual" and "unusual" (NEMA MG 1-1998, 14.2 - 14.3).

■ **Usual.** Usual service conditions include:

- Exposure to an ambient temperature within the range of -15° to 40° C (5° to 104° F).
- Installation in areas or supplementary enclosures which do not seriously interfere with the ventilation of the motor.
- Operation within a tolerance of ±10% of rated voltage.
- Operation within a tolerance of ±5% of rated frequency.
- Installation on a rigid mounting surface.
- Exposure to an altitude that does not exceed 3300 feet (1000 meters).
- Operation from a sine wave voltage source.

- Operation with a voltage unbalance of 1% or less.

■ **Unusual.** Unusual service conditions which may affect the construction or operation of a motor include, but are not limited to:

- Exposure to combustible, explosive, abrasive, or conducting dusts.
- Exposure to lint or very dirty operating conditions where the accumulation may interfere with normal ventilation.
- Exposure to chemical fumes, flammable or explosive gases, nuclear radiation.
- Exposure to steam, salt-laden air, or oil vapor.
- Exposure to damp or very dry locations, radiant heat, vermin infestation, or atmospheres conducive to the growth of fungus.
- Exposure to abnormal shock, vibration, or mechanical loading from external sources.
- Exposure to abnormal axial or side thrust imposed on the motor shaft.
- Operation where there is excessive departure from rated voltage or frequency, or both.
- Operation where the power system is not grounded.
- Operation at speeds above the highest rated speed.
- Operation in a poorly ventilated room, in a pit, or in an inclined position.
- Operation where subjected to: torsional impact loads, repetitive abnormal overloads, reversing or electric braking, frequent starting.

Consult the manufacturer or a local EASA service center if any unusual service conditions exist which may affect the construction or operation of the motor.

Voltage

■ **Incorrect Voltage.** In addition to a thorough maintenance and testing program, one of the best ways to guarantee economical performance and long motor life is to make sure the motors operate at nameplate voltage. Operating a motor at other than nameplate voltage may reduce its efficiency. This, in turn, shortens motor life by overheating the insulation and lubrication systems.

Operating at below nameplate voltage reduces the motor's effective horsepower. For example, a motor operated at 10% below rated voltage produces about three-quarters of its design torque. The motor will try to drive the intended load, become overloaded, draw more current and overheat. The result: premature failure.

■ **Unbalanced Voltages.** Operating a three-phase AC motor with unbalanced voltage or on an open-delta distribution system also can cause serious overheating that will shorten its life dramatically (NEMA MG 1-1998, 14.36). How much hotter a three-phase motor will become when operating on an unbalanced system can be computed with this formula:

$$2 \times (\%\ \text{voltage unbalance})^2 = \%\ \text{additional temperature rise}^*$$

*This formula is an estimation and is not a NEMA standard.

Generally speaking, each 10° C rise above the rated temperature cuts motor life by half. An increase of 20° C above rated temperature, therefore, would reduce motor life to about one-fourth of normal.

Example. A motor operating with a 3.5% voltage unbalance will experience an additional temperature rise of approximately 25% above its rated temperature rise ($2 \times 3.5^2 = 24.5$). A standard, totally-enclosed, fan-cooled T-frame motor has a temperature rise of about 75° C. An increase of 25% in this case would raise the operating temperature about 19° C (75 x .25 = 18.75).

When voltage unbalance exceeds 1%, NEMA stipulates that a motor should be derated in order to operate successfully. The derating curve shown below indicates that at the 5% limit established by NEMA for unbalance, a motor would have to be substantially derated, to only 75% of its nameplate horsepower rating. Even then, proper starter overload protection would be difficult to choose.

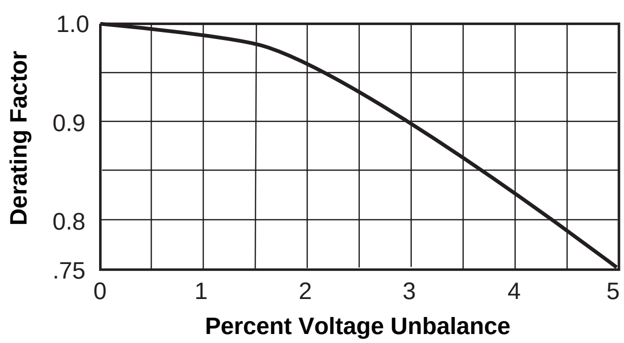


Figure 3. NEMA Derating Curve
(NEMA MG 1-1998, Figure 14-1)

Construction Features

■ **Motor Enclosures.** There are two types of motor enclosures: open and enclosed. Most open motors are of dripproof construction, defined by NEMA as motors with openings such that liquid or solid particles falling on the motor at up to a 15-degree angle from the vertical will not enter or harm the motor (NEMA MG 1-1998, 1.25). Enclosed motors are just that; they have no direct openings from the outside to the interior (NEMA MG 1-1998, 1.26). The most common of these are totally enclosed, fan-cooled (TEFC), with variations being totally enclosed, non-ventilated (TENV) and explosion-proof (XP) for hazardous locations.

Dripproof motors are suitable for clean and moderately dirty or moist locations. Typical applications include air handlers and pumps inside buildings. Totally enclosed motors are designed for harsher environments, typically outdoors or in an industrial environment.

■ **Shaft Designations.** Shaft extensions are designated as a suffix to the basic motor frame size. The current designations for standard shafts are “T” and “TS” (NEMA MG 1-1998, 4.2.2).

The “TS” indicates a short shaft intended for direct connection— i.e., coupling. The “TS” is not suitable for use with sheaves, pinions, or sprockets due to their relatively high radial load. Typically, the “TS” will have a standard ball bearing on the drive end.

The “T” shaft is greater in diameter and length than the “TS”, and is intended for use with V-belt sheaves, gear pinions, and chain sprockets. The “T” will use a larger or maximum-capacity ball bearing, or possibly a roller bearing. The “T” may be used for direct connection.

Caution: A cylindrical roller bearing may not be suitable for direct connection because the bearing needs radial load to prevent the rollers from “skidding” (momentary stoppage of rotation).

The motor bearings and shaft can be overloaded by misaligned couplings; overtightened belts; or sheaves, chains, or sprockets that are too small in diameter.

■ **Winding Heaters.** Moisture is detrimental to long motor life because it can deteriorate the insulation. To prevent condensation, either of two common methods is usually effective. One is to install electric space heaters in the motor. The other is to apply a low DC voltage to one phase of the motor windings whenever the motor is at rest. With either method, the objective is to keep the temperature of the windings 5° to 10° C above the ambient temperature.

Application Considerations

■ **Motor Selection.** To extend motor life, be sure to use the right motor for the application (see Figure 4 and Table 2). For instance, for an application that requires starting a high-torque load, a standard, general purpose NEMA Design B motor might be inadequate. A Design C motor, which has more starting torque than either a Design A or Design B motor and yet draws about the same starting current, might be required. If a Design A or Design B motor were used on a high-torque application, the overload protectors might trip before the motor could accelerate the load to operating speed. Even if overload protectors permit the motor to reach running speed, motor life would be shortened due to the additional heat generated during the prolonged starting period. *Be careful not to mistake the insulation class letter or kVA code letter for the design letter.*

Energy efficient motors can trip some circuit breakers because they have higher inrush currents than standard motors.

Other features of the motor, besides torque, must be considered to match the driven load. These include rotating speed (rpm), supply power requirements, duty cycle, and the method of starting. The physical environment can introduce other factors, such as corrosives, moisture, temperature extremes, and position (e.g., vertical mounting).

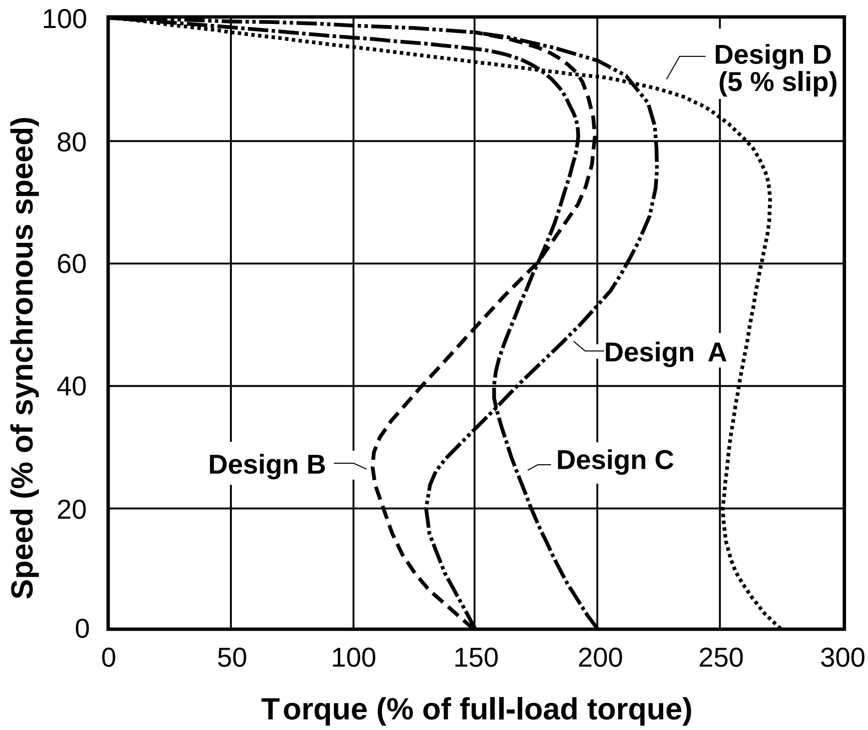


Figure 4. General Speed-Torque Characteristics

Table 2. NEMA Torque Designs For Three-Phase Motors

NEMA Design	Locked Rotor Torque	Breakdown Torque	Locked Rotor Current	Percent Slip	Relative Efficiency
B	70 - 275%*	175 - 300%*	600 - 700%	0.5-5%	Medium or High
	Applications: Fans, blowers, centrifugal pumps and compressors, motor-generator sets, etc., where starting torque requirements are relatively low.				
C	200 - 250%*	190 - 225%*	600 - 700%	1-5%	Medium
	Applications: Conveyors, crushers, stirring machines, agitators, reciprocating pumps and compressors, etc., where starting under load is required.				
D	275%	275%	600 - 700%	5 - 8% 8 - 13% 15 - 25%	Medium
	Applications: High peak loads with or without flywheels, such as punch presses, shears,elevators, extractors winches, hoists, oil-well pumping, and wire-drawing machines.				

Based on NEMA Standards MG 10, Table 2-1. NEMA Design A is a variation of Design B having higher locked-rotor current.

*Higher values are for motors having lower horsepower ratings.

■ **Continuous Duty Motors.** Continuous duty motors should not be used in applications that require frequent starting or reversing unless special provisions are made. These motors must be allowed to run long enough after each start to dissipate the heat that builds up as about six to eight times rated full-load current passes through the windings during the starting period.

■ **Allowable Number Of Motor Starts.** The inertia of the load, motor horsepower and speed (poles) determine the allowable number of times per hour a motor may be started (NEMA MG 1-1998, 12.55). Table 3 (Page 11) indicates the number of starts per hour and the minimum rest or "off time" between starts for a number of common motor ratings. It is based on starting at rated voltage and frequency, with a load Wk^2 and torque within limits shown in Table 4 (Page 12).

Table 3. Allowable Starts And Starting Intervals (Design A and B Motors)

HP	2 Pole			4 Pole			6 Pole		
	A	B	C	A	B	C	A	B	C
1	15	1.2	75	30	5.8	38	34	15	33
1.5	12.9	1.8	76	25.7	8.6	38	29.1	23	34
2	11.5	2.4	77	23	11	39	26.1	30	35
3	9.9	3.5	80	19.8	17	40	22.4	44	36
5	8.1	5.7	83	16.3	27	42	18.4	71	37
7.5	7.0	8.3	88	13.9	39	44	15.8	104	39
10	6.2	11	92	12.5	51	46	14.2	137	41
15	5.4	16	100	10.7	75	50	12.1	200	44
20	4.8	21	110	9.6	99	55	10.9	262	48
25	4.4	26	115	8.8	122	58	10.0	324	51
30	4.1	31	120	8.2	144	60	9.3	384	53
40	3.7	40	130	7.4	189	65	8.4	503	57
50	3.4	49	145	6.8	232	72	7.7	620	64
60	3.2	58	170	6.3	275	85	7.2	735	75
75	2.9	71	180	5.8	338	90	6.6	904	79
100	2.6	92	220	5.2	441	110	5.9	1181	97
125	2.4	113	275	4.8	542	140	5.4	1452	120
150	2.2	133	320	4.5	640	160	5.1	1719	140
200	2.0	172	600	4.0	831	300	4.5	2238	265
250	1.8	210	1000	3.7	1017	500	4.2	2744	440

Where: A = Maximum number of starts per hour.
B = Maximum product of starts per hour times load Wk^2.
C = Minimum rest or off time in seconds between starts.
Allowable starts per hour is the lesser of (1) A or (2) B divided by the load Wk^2—i. e.,

Starts per hour $\leq A$ or $\leq B/Wk^2$, whichever is less.

Note: Table 3 is based on following conditions:

1. Applied voltage and frequency in accordance with MG 1-1998, 12.45.
2. During the accelerating period, the connected load torque is equal to or less than a torque which varies as the square of the speed and is equal to 100 percent of rated torque at rated speed.
3. External load Wk^2 equal to or less than the values listed in Column B.

For other conditions, consult the manufacturer.

Reference: NEMA Standards MG 10, Table 2-3.

Example: 25 horsepower motor, 4 poles, with an actual load Wk^2 of 50.

1. From the Table 3, A = 8.8 and B = 122.
2. Calculate $B/Wk^2 = 122/50 = 2.44$.
3. Since B/Wk^2 is less than A, the allowable starts per hour = 2.44.

4. From Table 3, C = 58.
5. The minimum rest or "off time" between starts is therefore 58 seconds.

Table 4. Allowable Load Wk^2 (Squirrel-Cage Induction Motors)

HP	Synchronous Speed, RPM 3600	1800	1200	900	720	600	514
	Allowable Load Wk^2 (Exclusive of Motor Wk^2), $LB\text{-}FT^2$						
1	—	5.8	15	31	53	82	118
1.5	1.8	8.6	23	45	77	120	174
2	2.4	11	30	60	102	158	228
3	3.5	17	44	87	149	231	335
5	5.7	27	71	142	242	375	544
7.5	8.3	39	104	208	356	551	798
10	11	51	137	273	467	723	1048
15	16	75	200	400	685	1061	1538
20	21	99	262	525	898	1393	2018
25	26	122	324	647	1108	1719	2491
30	31	144	384	769	1316	2042	2959
40	40	189	503	1007	1725	2677	3881
50	49	232	620	1241	2127	3302	4788
60	58	275	735	1473	2524	3819	5680
75	71	338	904	1814	3111	4831	7010
100	92	441	1181	2372	4070	6320	9180
125	113	542	1452	2919	5010	7790	11310
150	133	640	1719	3456	5940	9230	—
200	172	831	2238	4508	7750	—	—
250	210	1017	2744	5540	—	—	—
300	246	1197	3239	—	—	—	—
350	281	1373	3723	—	—	—	—
400	315	1546	—	—	—	—	—
450	349	1714	—	—	—	—	—
500	381	1880	—	—	—	—	—

Reference: NEMA MG 1, Table 12-6.

The allowable Wk^2 is the moment of inertia of the load, referred to the motor shaft. The manufacturer of the driven machinery can usually provide the load Wk^2 value.

■ **Alternative Starting Methods.** Using a clutch to engage and disengage the drive allows the motor to continue running and eliminates the heat generated by a succession of starts. Starting devices such as solid-state or electromechanical reduced-voltage starters can reduce some stresses associated with motor starting. By doing so, they may help motors last longer. However, they generally don't increase the number of allowable starts per hour.

Adjustable-speed drives reduce mechanical stresses but usually increase the electrical and thermal stresses in motors. Harmonics generated by such drives are the primary cause of these stresses.

■ **Transient Torques, Voltages And Currents.** Under certain conditions, motors can develop dangerous transient torques, which can range from 5 to 20 times the rated torque of the motor. The most common causes of these torques (and also transient voltages and currents) are:

- Bus transfer and out-of-phase reclosures
- Plug reversals
- Transfer from high to lower speed of multispeed windings
- External short circuits
- Switching of power factor equipment
- Overcorrection with power factor capacitors
- Adjustable-speed drives

Finding the right solutions for such complex problems requires specialized knowledge. Contact an EASA service center or the machinery manufacturer for assistance.

Installation

Safety First! Lock out and tag out the electrical supply before removing or installing a motor.

■ **Basic Considerations.** When preparing to remove or install a motor, consider safety first. Always lock out and tag out the electrical supply to the motor before starting work.

Next, make certain an adequate supply of cooling air will reach the motor. If not, provide a filtered air supply with sufficient airflow.

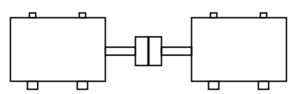
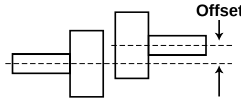
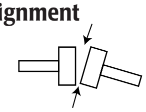
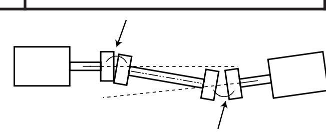
The foundation, whether a concrete pad or a steel frame, should be free of cracks and strong enough to support the motor and base. The base may be as simple as raised pads on a steel frame. For V-belt installations, the base usually provides a means of sliding the motor to increase or decrease belt tension. (A level base generally works best, especially if the motor is oil-lubricated.)

Make sure all electrical connections are tight and properly insulated, and that the motor is properly grounded. Connect the motor leads for the supply voltage as indicated by the motor manufacturer. Then run the motor uncoupled to verify the direction of rotation and to measure the no-load current.

Now install V-belts or couple the motor to the driven load. Rotate the shaft manually to be sure that no problems have occurred in the driven load, or in the belt or coupling installation. Proper shaft alignment and mechanical placement will reduce vibration, maximize bearing life, and increase the overall life of the motor and driven machine. To prevent frame distortion, increased vibration and reduced bearing life, correct for "soft foot" when mounting the motor.

■ **Suggested Alignment Tolerances.** Use dial indicators or laser systems to check the alignment of directly-coupled shafts. The following suggested alignment tolerances are the desired values, whether such values are zero or a targeted offset. Use them only if machinery manufacturer alignment tolerances are not available.

Table 5. Suggested Alignment Tolerances For Directly-Coupled Shafts

	RPM	Installation	In Service
Soft Foot (mils)*	All	±1.0	±1.5
Short Couplings			
Parallel Offset (mils) 	**RPM**	**Installation**	**In Service**
	1200	±1.25	±2.0
	1800	±1.0	±1.5
	3600	±0.5	±0.75
Angular Misalignment (mils/inch)** 	1200	0.5	0.8
	1800	0.3	0.5
	3600	0.2	0.3
Couplings With Spacers			
	RPM	**Installation**	**In Service**
Parallel Offset Per Inch of Spacer Length (mils/inch)	1200	0.9	1.5
	1800	0.6	1.0
	3600	0.3	0.5

* "Soft foot" describes the condition where the mounting feet are not all in the same plane. Measured in mils (1 mil. = .001 inches).

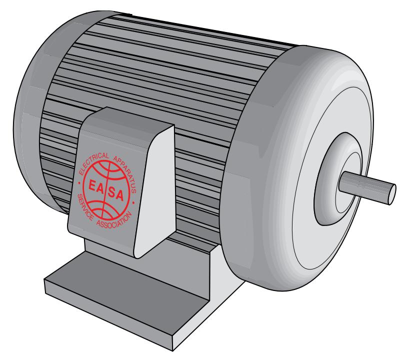
** To find the angular misalignment in mils/inch of coupling diameter, measure the widest opening in mils, then subtract the narrowest opening in mils, and divide by the diameter of the coupling in inches. (Note: Up and down motion of driving and driven shafts with temperature may be in either direction.)

■ **Belt Tension.** On belt installations, set the belt tension to the required range and check it after one day of operation. Belt tension commonly decreases shortly after installation, particularly if the belts are new. (Note that belt installations, like directly-coupled shafts, must be aligned properly. See EASA's *Mechanical Reference Handbook* for more information.)

Confirm that all mechanical guards and electrical box covers have been reinstalled correctly. Verify that the motor load current is within the nameplate rating for the applicable voltage. Verify that the alignment and mechanical balance are acceptable by taking vibration readings after the installation is complete. These vibration and current readings create a baseline for future reference.

Spare Motors

To keep downtime to a minimum, it is a good idea to have spare motors on hand for equipment that is vital to plant operation.



■ **Storage.** Store spare motors in a dry, vibration-free area. Rotate the shafts periodically (preferably monthly, but at least quarterly) to keep lubricant on the bearings. This will help prevent oxidation and bearing damage. Apply a protective coating to the shafts.

Prevent condensation by storing the motors in a temperature-controlled area, if necessary. Performing insulation resistance tests at regular intervals will ensure that the motor's insulation systems have not deteriorated.

Repair vs. Replacement

All motor failures should be analyzed to determine the cause. Premature bearing failure, for example, may indicate that the bearing type is not adequate for the application.

■ **Frame Assignments.** In deciding whether to repair or replace a standard motor, first determine the frame number of the present motor from its nameplate. The frame designations of motors manufactured to NEMA standards are shown in Table 6.

See Tables 7, 8 and 9 (Pages 17-19) for a listing of NEMA frame assignments and dimensions. Frame dimensions used by the International Electrotechnical Commission (IEC) are listed in Table 10 (Page 20). Replacing an earlier frame motor with a new motor will require adaptation. This, of course, must be figured into the replacement cost.

If a motor winding has failed, consider the economics of buying a new, energy efficient motor versus the cost to rewind. For guidance on repair and replace considerations, see EASA's *A Guide To AC Motor Repair And Replacement*. The term "energy efficient" describes a motor that meets a minimum full-load efficiency defined by NEMA.

Table 6. NEMA Frame Designations

NEMA Frame Designations	Description
Original NEMA Frame	Motors manufactured to NEMA standards through 1952
1952 Rerate ("U" Frame)	Motors produced to NEMA standards between 1953 and 1964
1964 Rerate ("T" Frame)	Motors produced to NEMA standards after 1964

Often, repairing a motor has advantages over replacement. Adaptation costs, for example, are eliminated. In most cases, the insulation system in the repaired equipment will have a higher temperature rating, which will extend winding life. EASA service centers offer repairs that meet *ANSI/EASA Standard AR100-1998 Recommended Practice for the Repair of Rotating Electrical Apparatus*. They also can help with the repair/replace decision by calculating energy costs using manufacturers' efficiency ratings.

■ **New Motor Specifications.** Some points to consider when specifying a new motor are:

- ✔ Horsepower
- ✔ Power system conditions
- ✔ Mounting position
- ✔ Load inertia
- ✔ Bearing type
- ✔ Torque (design letter)
- ✔ Ambient temperature
- ✔ Enclosure
- ✔ Speed (poles)
- ✔ Efficiency
- ✔ Conduit box location
- ✔ Coupling vs. pulley drive
- ✔ Lubrication
- ✔ Service factor
- ✔ Unusual service conditions
- ✔ Dimensional constraints

Assess the effectiveness of the existing motor's enclosure. Changing from dripproof to totally enclosed fan-cooled (TEFC) may provide more protection against contaminants that could degrade windings and bearings. (Caution: although a TEFC motor may be the same frame size as the dripproof motor it is intended to replace, its overall dimensions may be larger.)

If the load requirement is less than half the motor horsepower rating, efficiency may be improved by purchasing a lower horsepower motor. It also may be possible to redesign and rewind the motor for the lower horsepower requirement.

Be sure to look at possible changes in process control that could mean a larger payback than a motor changeout alone. Remember, the ultimate energy saver is a motor that's turned off.

Table 7. NEMA Frame Assignments
Three-Phase Open Motors–General Purpose

HP	3600 RPM			1800 RPM			1200 RPM			900 RPM		
NEMA Program	Orig.	1952 Rerate	1964 Rerate	Orig.	1952 Rerate	1964 Rerate	Orig.	1952 Rerate	1964 Rerate	Orig.	1952 Rerate	1964 Rerate
1	—	—	—	203	182	143T	204	184	145T	225	213	182T
1.5	203	182	143T	204	184	145T	224	184	182T	254	213	184T
2	204	184	145T	224	184	145T	225	213	184T	254	215	213T
3	224	184	145T	225	213	182T	254	215	213T	284	254U	215T
5	225	213	182T	254	215	184T	284	254U	215T	324	256U	254T
7.5	254	215	184T	284	254U	213T	324	256U	254T	326	284U	256T
10	284	254U	213T	324	256U	215T	326	284U	256T	364	286U	284T
15	324	256U	215T	326	284U	254T	364	324U	284T	365	326U	286T
20	326	284U	254T	364	286U	256T	365	326U	286T	404	364U	324T
25	364S	286U	256T	364	324U	284T	404	364U	324T	405	365U	326T
30	364S	324S	284TS	365	326U	286T	405	365U	326T	444	404U	364T
40	365S	326S	286TS	404	364U	324T	444	404U	364T	445	405U	365T
50	404S	364US	324TS	405S	365US	326T	445	405U	365T	504U	444U	404T
60	405S	365US	326TS	444S	404US	364TS†	504U	444U	404T	505	445U	405T
75	444S	404US	364TS	445S	405US	365TS†	505	445U	405T	—	—	444T
100	445S	405US	365TS	504S	444US	404TS†	—	—	444T	—	—	445T
125	504S	444US	404TS	505S	445US	405TS†	—	—	445T	—	—	—
150	505S	445US	405TS	—	—	444TS†	—	—	—	—	—	—
200	—	—	444TS	—	—	445TS†	—	—	—	—	—	—
250	—	—	445TS	—	—	—	—	—	—	—	—	—

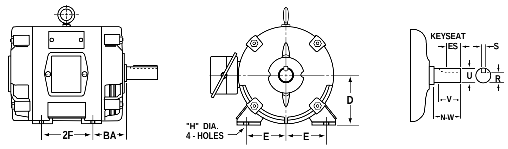
† When motors are to be used with V-belt or chain drives, the correct frame size is the one shown but with the suffix letter S omitted. For the corresponding shaft extension dimensions, see Pages 18-19.

Table 8. NEMA Frame Assignments
Three-Phase TEFC Motors–General Purpose

HP	3600 RPM			1800 RPM			1200 RPM			900 RPM		
NEMA Program	Orig.	1952 Rerate	1964 Rerate	Orig.	1952 Rerate	1964 Rerate	Orig.	1952 Rerate	1964 Rerate	Orig.	1952 Rerate	1964 Rerate
1	—	—	—	203	182	143T	204	184	145T	225	213	182T
1.5	203	182	143T	204	184	145T	224	184	182T	254	213	184T
2	204	184	145T	224	184	145T	225	213	184T	254	215	213T
3	224	184	182T	225	213	182T	254	215	213T	284	254U	215T
5	225	213	184T	254	215	184T	284	254U	215T	324	256U	254T
7.5	254	215	213T	284	254U	213T	324	256U	254T	326	284U	256T
10	284	254U	215T	324	256U	215T	326	284U	256T	364	286U	284T
15	324	256U	254T	326	284U	254T	364	324U	284T	365	326U	286T
20	326	286U	256T	364	286U	256T	365	326U	286T	404	364U	324T
25	365S	324U	284TS	365	324U	284T	404	364U	324T	405	365U	326T
30	404S	326S	286TS	404	326U	286T	405	365U	326T	444	404U	364T
40	405S	364US	324TS	405	364U	324T	444	404U	364T	445	405U	365T
50	444S	365US	326TS	444S	365US	326T	445	405U	365T	504U	444U	404T
60	445S	405US	364TS	445S	405US	364TS†	504U	444U	404T	505	445U	405T
75	504S	444US	365TS	504S	444US	365TS†	505	445U	405T	—	—	444T
100	505S	445US	405TS	505S	445US	405TS†	—	—	444T	—	—	445T
125	—	—	444TS	—	—	444TS†	—	—	445T	—	—	—
150	—	—	445TS	—	—	445TS†	—	—	—	—	—	—

† When motors are to be used with V-belt or chain drives, the correct frame size is the one shown but with the suffix letter S omitted. For the corresponding shaft extension dimensions, see Pages 18-19.

Table 9. NEMA Frame Dimensions*
Foot-Mounted AC Machines



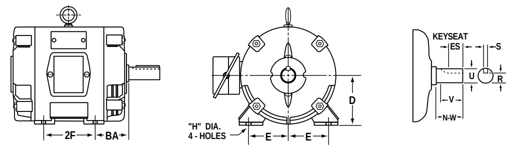
* Dimensions in inches

Frame Number	D	E	2F	BA	H**	U	N-W	V Min.	Keyseat		
									R	ES Min.	S
42	2.62	1.75	1.69	2.06	0.28	0.3750	1.12		0.328		Flat
48	3.00	2.12	2.75	2.50	0.34	0.5000	1.50		0.453		Flat
48H	3.00	2.12	4.75	2.50	0.34	0.5000	1.50		0.453		Flat
56	3.50	2.44	3.00	2.75	0.34	0.6250	1.88		0.517	1.41	0.188
56H	3.50	2.44	5.00	2.75	0.34	0.6250	1.88		0.517	1.41	0.188
66	4.12	2.94	5.00	3.12	0.41	0.7500	2.25		0.644	1.91	0.188
143	3.50	2.75	4.00	2.25	0.34	0.7500	2.00	1.75	0.644	1.41	0.188
143T	3.50	2.75	4.00	2.25	0.34	0.8750	2.25	2.00	0.771	1.41	0.188
145	3.50	2.75	5.00	2.25	0.34	0.7500	2.00	1.75	0.644	1.41	0.188
145T	3.50	2.75	5.00	2.25	0.34	0.8750	2.25	2.00	0.771	1.41	0.188
182	4.50	3.75	4.50	2.75	0.41	0.8750	2.25	2.00	0.771	1.41	0.188
182T	4.50	3.75	4.50	2.75	0.41	1.1250	2.75	2.50	0.986	1.78	0.250
184	4.50	3.75	5.50	2.75	0.41	0.8750	2.25	2.00	0.771	1.41	0.188
184T	4.50	3.75	5.50	2.75	0.41	1.1250	2.75	2.50	0.986	1.78	0.250
203	5.00	4.00	5.50	3.12	0.41	0.7500	2.25	2.00	0.644	1.53	0.188
204	5.00	4.00	6.50	3.12	0.41	0.7500	2.25	2.00	0.644	1.53	0.188
213	5.25	4.25	5.50	3.50	0.41	1.1250	3.00	2.75	0.986	2.03	0.250
213T	5.25	4.25	5.50	3.50	0.41	1.3750	3.38	3.12	1.201	2.41	0.312
215	5.25	4.25	7.00	3.50	0.41	1.1250	3.00	2.75	0.986	2.03	0.250
215T	5.25	4.25	7.00	3.50	0.41	1.3750	3.38	3.12	1.201	2.41	0.312
224	5.50	4.50	6.75	3.50	0.41	1.0000	3.00	2.75	0.859	2.03	0.250
225	5.50	4.50	7.50	3.50	0.41	1.0000	3.00	2.75	0.859	2.03	0.250
254	6.25	5.00	8.25	4.25	0.53	1.1250	3.38	3.12	0.986	2.03	0.250
254U	6.25	5.00	8.25	4.25	0.53	1.3750	3.75	3.50	1.201	2.78	0.312
254T	6.25	5.00	8.25	4.25	0.53	1.625	4.00	3.75	1.416	2.91	0.375
256U	6.25	5.00	10.00	4.25	0.53	1.3750	3.75	3.50	1.201	2.78	0.312
256T	6.25	5.00	10.00	4.25	0.53	1.625	4.00	3.75	1.416	2.91	0.375
284	7.00	5.50	9.50	4.75	0.53	1.2500	3.75	3.50	1.112	2.03	0.250
284U	7.00	5.50	9.50	4.75	0.53	1.625	4.88	4.62	1.416	3.78	0.375
284T	7.00	5.50	9.50	4.75	0.53	1.875	4.62	4.38	1.591	3.28	0.500
284TS	7.00	5.50	9.50	4.75	0.53	1.625	3.25	3.00	1.416	1.91	0.375
286U	7.00	5.50	11.00	4.75	0.53	1.625	4.88	4.62	1.416	3.78	0.375
286T	7.00	5.50	11.00	4.75	0.53	1.875	4.62	4.38	1.591	3.28	0.500
286TS	7.00	5.50	11.00	4.75	0.53	1.625	3.25	3.00	1.416	1.91	0.375
324	8.00	6.25	10.50	5.25	0.66	1.625	4.88	4.62	1.416	3.78	0.375
324U	8.00	6.25	10.50	5.25	0.66	1.875	5.62	5.38	1.591	4.28	0.500
324S	8.00	6.25	10.50	5.25	0.66	1.625	3.25	3.00	1.416	1.91	0.375
324T	8.00	6.25	10.50	5.25	0.66	2.125	5.25	5.00	1.845	3.91	0.500
324TS	8.00	6.25	10.50	5.25	0.66	1.875	3.75	3.50	1.591	2.03	0.500
326	8.00	6.25	12.00	5.25	0.66	1.625	4.88	4.62	1.416	3.78	0.375
326U	8.00	6.25	12.00	5.25	0.66	1.875	5.62	5.38	1.591	4.28	0.500
326S	8.00	6.25	12.00	5.25	0.66	1.625	3.25	3.00	1.416	1.91	0.375
326T	8.00	6.25	12.00	5.25	0.66	2.125	5.25	5.00	1.845	3.91	0.500
326TS	8.00	6.25	12.00	5.25	0.66	1.875	3.75	3.50	1.591	2.03	0.500

Reference: NEMA Standards MG 1-1998, 4.4.1.

**Frames 42 to 66, inclusive: the H dimension is Width of Slot. Frames 143 to 505S, inclusive: the H dimension is Diameter of Hole.

Table 9. NEMA Frame Dimensions*
Foot-Mounted AC Machines–Continued



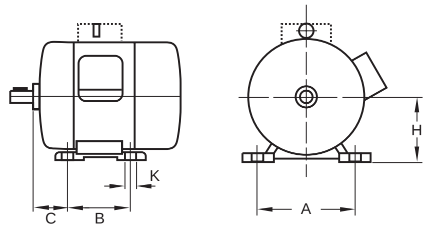
* Dimensions in inches

Frame Number	D	E	2F	BA	H**	U	N-W	V Min.	Keyseat		
									R	ES Min.	S
364	9.00	7.00	11.25	5.88	0.66	1.875	5.62	5.38	1.591	4.28	0.500
364S	9.00	7.00	11.25	5.88	0.66	1.625	3.25	3.00	1.416	1.91	0.375
364U	9.00	7.00	11.25	5.88	0.66	2.125	6.38	6.12	1.845	5.03	0.500
364US	9.00	7.00	11.25	5.88	0.66	1.875	3.75	3.50	1.591	2.03	0.500
364T	9.00	7.00	11.25	5.88	0.66	2.375	5.88	5.62	2.021	4.28	0.625
364TS	9.00	7.00	11.25	5.88	0.66	1.875	3.75	3.50	1.591	2.03	0.500
365	9.00	7.00	12.25	5.88	0.66	1.875	5.62	5.38	1.591	4.28	0.500
365S	9.00	7.00	12.25	5.88	0.66	1.625	3.25	3.00	1.416	1.91	0.375
365U	9.00	7.00	12.25	5.88	0.66	2.125	6.38	6.12	1.845	5.03	0.500
365US	9.00	7.00	12.25	5.88	0.66	1.875	3.75	3.50	1.591	2.03	0.500
365T	9.00	7.00	12.25	5.88	0.66	2.375	5.88	5.62	2.021	4.28	0.625
365TS	9.00	7.00	12.25	5.88	0.66	1.875	3.75	3.50	1.591	2.03	0.500
404	10.00	8.00	12.25	6.62	0.81	2.125	6.38	6.12	1.845	5.03	0.500
404S	10.00	8.00	12.25	6.62	0.81	1.875	3.75	3.50	1.591	2.03	0.500
404U	10.00	8.00	12.25	6.62	0.81	2.375	7.12	6.88	2.021	5.53	0.625
404US	10.00	8.00	12.25	6.62	0.81	2.125	4.25	4.00	1.845	2.78	0.500
404T	10.00	8.00	12.25	6.62	0.81	2.875	7.25	7.00	2.450	5.65	0.750
404TS	10.00	8.00	12.25	6.62	0.81	2.125	4.25	4.00	1.845	2.78	0.500
405	10.00	8.00	13.75	6.62	0.81	2.125	6.38	6.12	1.845	5.03	0.500
405S	10.00	8.00	13.75	6.62	0.81	1.875	3.75	3.50	1.591	2.03	0.500
405U	10.00	8.00	13.75	6.62	0.81	2.375	7.12	6.88	2.021	5.53	0.625
405US	10.00	8.00	13.75	6.62	0.81	2.125	4.25	4.00	1.845	2.78	0.500
405T	10.00	8.00	13.75	6.62	0.81	2.875	7.25	7.00	2.450	5.65	0.750
405TS	10.00	8.00	13.75	6.62	0.81	2.125	4.25	4.00	1.845	2.78	0.500
444	11.00	9.00	14.50	7.50	0.81	2.375	7.12	6.88	2.021	5.53	0.625
444S	11.00	9.00	14.50	7.50	0.81	2.125	4.25	4.00	1.845	2.78	0.500
444U	11.00	9.00	14.50	7.50	0.81	2.875	8.62	8.38	2.450	7.03	0.750
444US	11.00	9.00	14.50	7.50	0.81	2.125	4.25	4.00	1.845	2.78	0.500
444T	11.00	9.00	14.50	7.50	0.81	3.375	8.50	8.25	2.880	6.91	0.875
444TS	11.00	9.00	14.50	7.50	0.81	2.375	4.75	4.50	2.021	3.03	0.625
445	11.00	9.00	16.50	7.50	0.81	2.375	7.12	6.88	2.021	5.53	0.625
445S	11.00	9.00	16.50	7.50	0.81	2.125	4.25	4.00	1.845	2.78	0.500
445U	11.00	9.00	16.50	7.50	0.81	2.875	8.62	8.38	2.450	7.03	0.750
445US	11.00	9.00	16.50	7.50	0.81	2.125	4.25	4.00	1.845	2.78	0.500
445T	11.00	9.00	16.50	7.50	0.81	3.375	8.50	8.25	2.880	6.91	0.875
445TS	11.00	9.00	16.50	7.50	0.81	2.375	4.75	4.50	2.021	3.03	0.625
447T	11.00	9.00	20.00	7.50	0.81	3.375	8.50	8.25	2.880	6.91	0.875
447TS	11.00	9.00	20.00	7.50	0.81	2.375	4.75	4.50	2.021	3.03	0.625
449T	11.00	9.00	25.00	7.50	0.81	3.375	8.50	8.25	2.880	6.91	0.875
449TS	11.00	9.00	25.00	7.50	0.81	2.375	4.75	4.50	2.021	3.03	0.625
504U	12.50	10.00	16.00	8.50	0.94	2.875	8.62	8.38	2.450	7.28	0.750
504S	12.50	10.00	16.00	8.50	0.94	2.125	4.25	4.00	1.845	2.78	0.500
505	12.50	10.00	18.00	8.50	0.94	2.875	8.62	8.38	2.450	7.28	0.750
505S	12.50	10.00	18.00	8.50	0.94	2.125	4.25	4.00	1.845	2.78	0.500

Reference: NEMA Standards MG 1-1998, 4.4.1.

** Frames 42 to 66, inclusive: the H dimension is Width of Slot. Frames 143 to 505S, inclusive: the H dimension is Diameter of Hole.

Table 10. IEC Mounting Dimensions* Foot-Mounted AC and DC Machines



Frame Number	H	A	B	C	K	Bolt or Screw
56 M	2.20	3.55	2.80	1.40	0.23	M5
63 M	2.48	3.95	3.15	1.55	0.28	M6
71 M	2.79	4.40	3.55	1.75	0.28	M6
80 M	3.14	4.90	3.95	1.95	0.40	M8
90 S	3.54	5.50	3.95	2.20	0.40	M8
90 L	3.54	5.50	4.90	2.20	0.40	M8
100 S	3.93	6.30	4.40	2.50	0.48	M10
100 L	3.93	6.30	5.50	2.50	0.48	M10
112 S	4.40	7.50	4.50	2.75	0.48	M10
112 M	4.40	7.50	5.50	2.75	0.48	M10
132 S	5.19	8.50	5.50	3.50	0.48	M10
132 M	5.19	8.50	7.00	3.50	0.48	M10
160 S	6.29	10.00	7.00	4.25	0.58	M12
160 M	6.29	10.00	8.25	4.25	0.58	M12
160 L	6.29	10.00	10.00	4.25	0.58	M12
180 S	7.08	11.00	8.00	4.75	0.58	M12
180 M	7.08	11.00	9.50	4.75	0.58	M12
180 L	7.08	11.00	11.00	4.75	0.58	M12
200 S	7.87	12.50	9.00	5.25	0.73	M16
200 M	7.87	12.50	10.50	5.25	0.73	M16
200 L	7.87	12.50	12.00	5.25	0.73	M16
225 S	8.85	14.00	11.25	5.85	0.73	M16
225 M	8.85	14.00	12.25	5.85	0.73	M16
250 S	9.84	16.00	12.25	6.60	0.95	M20
250 M	9.84	16.00	13.75	6.60	0.95	M20
280 S	11.02	18.00	14.50	7.50	0.95	M20
280 M	11.02	18.00	16.50	7.50	0.95	M20
315 S	12.40	20.00	16.00	8.50	1.11	M24
315 M	12.40	20.00	18.00	8.50	1.11	M24
355 S	13.97	24.00	19.70	10.00	1.11	M24
355 M	13.97	24.00	22.05	10.00	1.11	M24
355 L	13.97	24.00	24.80	10.00	1.11	M24
400 S	15.74	27.00	22.05	11.00	1.38	M30
400 M	15.74	27.00	24.80	11.00	1.38	M30
400 L	15.74	27.00	27.95	11.00	1.38	M30

Reference: IEC 72-1 Standards.

* Dimensions, except for bolt and screw sizes, are shown in inches (rounded off). Bolt and screw sizes are shown in millimeters.

For tolerances on dimensions, see IEC 72-1, 6.1, Foot-Mounted Machines, Table 1. (Note: Data in IEC tables is shown in millimeters.)

Glossary

Ambient temperature—The temperature of the surrounding cooling medium. Commonly known as room temperature when the air is the cooling medium in contact with the equipment.

Base line—A measurement taken when a machine is in good operating condition that is used as a reference for monitoring and analysis.

Breakdown torque—The maximum torque that an AC motor will develop with rated voltage applied at rated frequency without an abrupt drop in speed. Also termed pull-out torque or maximum torque.

Efficiency—The ratio between useful work performed and the energy expended in producing it. It is the ratio of output power divided by the input power.

Full-load speed—The speed at which any rotating machine produces its rated output.

Full-load torque—The torque required to produce rated power at full-load speed.

General purpose motor—AC induction motor of 500 horsepower or less, open or enclosed construction, continuous duty, designed in standard ratings with standard characteristics for use under service conditions without restriction to a particular application (see NEMA MG 1-1998, 1.6.1).

Hertz (Hz)—The preferred terminology for cycles per second (frequency).

Horsepower—A unit for measuring the power of motors or the rate of doing work. One horsepower equals 33,000 foot-pounds of work per minute (550 ft•lbs per second) or 746 watts.

Insulation—Nonconducting materials separating the current-carrying parts of an electric machine from each other or from adjacent conducting material at a different potential.

Kilowatt (kW)—A unit of electrical power. Also, the output rating of motors manufactured and used off the North American continent.

Locked-rotor current—Steady-state current taken from the line with the rotor at standstill and at a rated voltage and frequency.

Locked-rotor torque—The minimum torque that a motor will develop at standstill for all angular positions of the rotor with rated voltage applied at rated frequency.

Megohmmeter—An instrument for measuring insulation resistance.

NEMA—National Electrical Manufacturers Association.

Poles—The magnetic poles set up inside an electric machine by the placement and connection of the windings.

Rated temperature rise—The permissible rise in temperature above ambient for an electric machine operating under load.

Rotor—The rotating element of any motor or generator.

Slip—The difference between synchronous and operating speeds, compared to synchronous speed, expressed as a percentage. Also the difference between synchronous and operating speeds, expressed in rpm.

Soft foot—The condition where the mounting feet of a motor and the pads of the base are not all in the same plane.

Stator—The stationary part of a rotating electric machine. Commonly used to describe the stationary part of an AC machine that contains the power windings.

Synchronous speed—The speed of the rotating machine element of an AC motor that matches the speed of the rotating magnetic field created by the armature winding.

Synchronous speed = (Frequency x 120)/(Number of poles)

Torque—The rotating force produced by a motor. The units of torque may be expressed as pound-foot, pound-inch (English system), or newton-meter (metric system).

Trending—Analysis of the change in measured data over at least three data measurement intervals.

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